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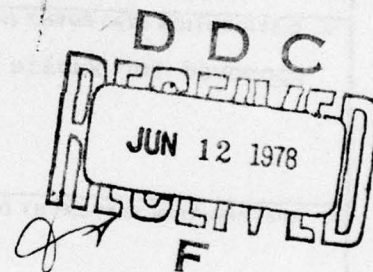
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actions which are about an order of magnitude smaller ($J = -0.8$ cm^{-1}) than
the glycinato analogue; in addition, the choice between the pair model and
the linear chain model is much less certain. The similarities and differences
in the interactions present in both compounds are compared to their known
crystallographic structures. The possibility of long range magnetic ordering
in strong applied magnetic fields and of unusual adiabatic cooling are
postulated for [Cu(N-sal=gly)H$_2$O]0.5H$_2$O.

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UNUSUAL MAGNETIC PROPERTIES IN TWO COPPER(II)
CHELATES OF SCHIFF BASES DERIVED FROM α-AMINO
ACIDS: A DIMERIC INTERACTION IN A STRUCTURAL
LINEAR CHAIN.

by William E. Estes and William E. Hatfield[*]

Abstract

The magnetic properties of two unusual Schiff base copper(II)

chelates, N-salicyledeneglycinatoaquocopper(II) hemihydrate and N-

salicyledene-α-aminoisobutyratoaquocopper(II), have been measured as a

function of temperature (1.6-160 K) and applied field strength (10-50 kOe).

The data reveal that the exchange interaction in $[Cu(N-sal=gly)H_2O]0.5H_2O$

is predominately between pairs of copper(II) ions in different struc-

tural chains rather than between an infinite linear array of copper(II)

ions along the obvious crystallographic chain; in moderate magnetic fields.

The dimer model yields an exchange energy, J, of -2.19 cm^{-1} with the inter-

cluster exchange being only about -0.09 cm^{-1}. High-field isothermal mag-

netization data with the applied field stronger than the exchange energy,

$H > 2J/g\beta$ indicate that the intercluster terms become significant as

longer range interactions occur when the ground state multiplicity changes.

The data for the structurally similar $[Cu(N-sal=aiba)H_2O]$ complex reveal

interactions which are about an order of magnitude smaller (J = -0.8 cm^{-1})

than the glycinato analogue; in addition, the choice between the pair model

and the linear chain model is much less certain. The similarities and

differences in the interactions present in both compounds are compared
to their known crystallographic structures. The possibility of long
range magnetic ordering in strong applied magnetic fields and of
unusual adiabatic cooling are postulated for $[Cu(N-sal-gly)H_2O]0.5H_2O$.

INTRODUCTION

Ordinarily one expects the structural and magnetic properties of a
given substance to be intimately related,[1-6] with the dimensionality of
the magnetic or electrical interactions that are present reflecting the
lattice   dimensionality. For example, a cluster of two interacting
magnetic ions should obey a theoretical model whose statistics treat only
the pair of interacting spins. Systems in which there are interactions
between a small number of spins in a definable cluster within a macroscopic
crystal are considered to be zero-dimensional (0-D) from a lattice view-
point. Each cluster is assumed to be isolated from neighboring clusters
in the crystal structure, and interactions of spins of the individual
clusters with the spins on neighboring clusters are assumed to be absent.
This basic idea may be generalized to include one dimensional chains (1-D)
and two-dimensional layers (2-D). Eventually such a process leads to the
ultimate reality of a three-dimensional (3-D) crystal structure in which
there are more or less equally interacting near neighbors.

The above simplified description of the effects of lattice dimension-
ality on the isotropic Heisenberg exchange interaction rarely applies to
real chemical systems.[3,6-8] Crystal packing requirements and weak inter-
unit bonding or hydrogen-bonding often occur and these features can give
rise to additional pathways for electrical[4] or exchange interactions[3]
between electrons on different units. The consequences of these additional
pathways for interactions lead to magnetic lattice dimensionality "cross-
overs" and eventually to long range magnetic order[9] or superconductivity.[4]
For example, dichlorobispyridinecopper(II), Cu(pyridine)$_2$Cl$_2$, is a 1-D
magnetic chain whose intrachain exchange, J, is much stronger than the
interchain exchange, J', Nonetheless, the small coupling between chains
is sufficiently strong to cause long range magnetic order at very low temp-
eratures.[10] Most of the experimental results to date[3,7-10] have been con-
cerned with systems which show an increase in "magnetic dimensionality"
as the temperature is lowered. It is of importance to note that the
reverse situation, a lattice dimensionality decrease, can also occur.
The Peierls[11] or "spin-Peierls"[12] transition can take a 1-D ensemble, via
an appropriate distortion, to a 0-D dimerized array.

It is of considerable interest to study systems which display one
type of structural dimensionality but another form of "magnetic dimension-
ality". Historically, the most famous example is Cu(NO$_3$)$_2$·2.5 H$_2$O. In
a series of elegant experiments, Friedberg and his co-workers have shown
that the zero-field susceptibility,[13] magnetic specific heat[14] and high-
field isothermal magnetization[15] could be rather well described by a simple
model of two copper(II) ions coupled by weak Heisenberg isotropic exchange

plus a small _interdimer_ exchange. From three independent measurements prior to 1970 (some of which extended down to 0.5K), it was concluded that $Cu(NO_3)_2 \cdot 2.5 \ H_2O$ was a dimeric cluster with a singlet ground state lying about 3.5 cm^{-1} below an excited triplet state. However, later structural studies by Garaj[16] and Morosin[17] revealed that the molecular structure did not consist of discrete clusters of copper(II) ions, but was a zig-zag linear array of copper(II) ions bridged by oxygen atoms from a bidentate nitrate ion. A great deal of current interest in $Cu(NO_3)_2 \cdot 2.5$ H_2O has been generated because of its unusual cooling properties under adiabated demagnetization conditions,[18-22] and because of the unusual super-exchange pathways.[23] The unusual magnetic and cooling properties have stimulated a considerable amount of theoretical work aimed at trying to understand the subtle exchange processes present in this compound.[24,25] Quite recently Von Tol et al.[26] have shown conclusively that $Cu(NO_3)_2 \cdot 2.5$ H_2O does show long-range magnetic order but only over a limited range of strong external fields near the point where the lowest component of the excited triplet state crosses the ground singlet.

Recent investigations in our laboratories have also revealed several examples of compounds with noncongruent structural and magnetic dimensional-ities. The magnetic properties of $Cu(NH_3)_2CO_3$, a compound in which copper-(II) ions are bridged by carbonate ligands to form chains,[27] may be described by a simple dimeric model even though there are only weak hydrogen bonds between chains.[28] Likewise, the structural data for the dichloro- and dibromo[2-(2-aminoethyl)pyridine]copper(II) complexes reveal a "ladder-like" arrangement with strongly bound dimers forming the rungs of the ladder while weaker out-of-plane halide bridges form the sides.[29,30] The

observed magnetic properties are best described by an alternating chain model[32] or a "spin-ladder"[24] since neither the pair nor the linear models are appropriate.

Two additional compounds, N-salicyledeneglycinatoaquocopper(II) hemihydrate[33], and N-salicyledene-α-aminoisobutyratoaquocopper(II),[34] have properties which yield information on this problem. Complexes of this general type (see Figure 1) have attracted considerable attention in recent years since they have been widely used as model systems for non-enzymatic transamination reactions in biological systems (for a comprehensive review of this aspect of the chemistry of these complexes see Rev. 35). The biochemical relevance of these compounds has stimulated crystallographic investigations of several members of the series, including the glycinato[36] and α-amino isobutyrato[37] derivatives mentioned above. The outstanding crystallographic features of both of these complexes are those of a structural linear chain of copper ions bridged by carboxylate oxygen atoms, but, as shown in this article, the magnetic properties of these species are quite different from those expected from the structural data.

EXPERIMENTAL

Preparation of the Complexes. [Cu(N-sal-gly)H_2O)·1/2 H_2O: Since there is some confusion in the literature concerning the preparation of this complex,[33,38,39a,b] we give here the details of the procedure used in this study.

Glycine 6.10 g (0.08 M)   was dissolved in a small amount of water (~50 ml). The solution was filtered and added slowly to a solution of

salicylaldehyde (0.08M) in 95% ethanol at 70°C; this mixture was stirred vigorously for ten minutes and then treated with additional portions of water to keep the Schiff's base in solution. A solution of copper acetate monohydrate (0.08 M) in the minimum amount of water was then added to the stirred solution of the Schiff base. Large quantities of a bright green needle-like product separated over a period of 20 minutes. Apparently this bright green material is [Cu(N-sal=gly)H$_2$O]·4H$_2$O,[40] since the color and morphology of the crystals appear identical. The desired complex was obtained by slow crystallization ($\sim$ 3 weeks) of the above product from a mixture of aqueous ethanol (H$_2$O:ethanol, 2:1, v/v) at room temperature. Very small dark green prisms were carefully harvested and allowed to air dry. Anal. Calcd. for [Cu(C$_9$H$_2$NO$_3$)H$_2$O]·0.5H$_2$O: C = 40.38; H = 3.76; N = 5.23. Found: C = 40.68; H = 4.0; N = 5.20.

Cu(N-sal = α-aiba)H$_2$O: This complex was prepared and recrystallized by Nakahara's method.[34] Anal. Calcd. for Cu(C$_{11}$H$_{11}$NO$_4$)·H$_2$O: C = 46.07; H = 4.57; Found: C = 45.87; H = 4.42. Microanalyses of both compounds were performed by Galbraith Laboratories, Inc., Knoxville, Tennessee.

Physical Measurements: Susceptibility and isooestic (constant field) magnetization measurements were made on finely powdered samples using a PAR model 155 VSM; details of the temperature measurements and calibrations of the magnetometer are described in detail elsewhere.[41] These measurements were carried out at field strengths of 10 kOe.

High-field isothermal magnetization data were obtained from a PAR model 150-A VSM from 10-50 kOe. Data collected at 4.2K were obtained by flooding

the sample zone with liquid helium and collecting the data point by point in both increasing and decreasing fields; the superconducting solenoid was placed in the persistent mode for approximately one minute during collection of each data point. For temperatures below 4.2K, the sample and sample zone were pumped down to a convenient temperature in zero applied field, the voltage across the GaAs diode thermometer was noted and recorded, and the pressure in the cryostat was measured by an external pressure gauge (Bourdon tube-type) attached to the cryostat vacuum line. The magnetic field was then energized to a desired value, a data point collected, and the pressure and the voltage across the diode monitored. Upon reaching the highest attainable field strength, the data were then re-collected with decreasing field strength, and the solenoid was de-energized. Once back at zero field, the temperature and pressure were again measured. If either the temperature (at H=0) or the "rough" pressure had changed (1-2%) during the isotherm, then the entire data set was considered to be in error and those data were discarded. The character-istics of our cryostat were such that the lowest attainable temperature ($\sim$1.4K) could not be maintained for extended time periods owing to overloading of the vacuum systems.

Electron paramagnetic resonance spectra were obtained on a Varian E-3 spectrometer operating at X-Band ($\sim$9.5GHz). Powder spectra were observed at room temperature and at 77 K. The magnetic field was cali-brated by nmr resonance techniques (^{1}H) using a Magnion G-502 precision gaussmeter and a Hewlett Packard 5340-A frequency counter.

RESULTS

The magnetization data for $Cu(N-sal-gly)H_2O \cdot 0.5H_2O$ are shown in Figures 2-4. Constant field data were collected at an applied field strength of 10kOe over the temperature range 1.6-160K (See Figures 2 and 3). The data are seen to go through a maximum near 3.5K and rapidly approach zero as T approaches zero. Surprisingly, this is just the behavior one expects for a simple spin pair coupled by a Heisenberg exchange interaction between centers. However, we must also emphasize that since the exchange energy is quite small, the effects of the applied magnetic field are noticeable only at low temperatures or in strong magnetic fields. Since the Zeeman energy at H=10kOe and the singlet-triplet splitting are of the same order of magnitude (~ 1 cm^{-1} and 4cm^{-1}, respectively), it should then be possible to force the lowest component of the triplet excited state (i.e. $M_s = -1$) to cross the singlet ground state when the Zeeman energy is larger than the zero field singlet-triplet splitting, $H > 2J/g\beta$ (see Figure 4 for the sketch of the zero field and Zeeman energies). We have measured the magnetization of the glycinato derivative along isotherms in applied fields below the zero-field, singlet-triplet splitting and have scanned through the region where the level crossing occurs; these data are shown in Figure 5. Inspection of the isothermal data does show an anomaly in the magnetization near 40 kOe at T = 1.72K. McGregor, et al.[41] and Berger, et al.[15] have discussed this phenomenon in detail and have presented excellent graphical representations which show these effects.

The magnetization data (10kOe) over the temperature interval from 1.6-130K for the aminoisobutyrato complex are shown in Figure 6. Even though

the available structural data show that the two compounds are very similar, the magnetization data are quite different. Indeed, close inspection of the lowest temperature data for $Cu(N\text{-sal-}\alpha\text{-aiba})H_2O$ fails to show any trace of a maximum. Thus, an interaction, if present, must be very small.

The values of the g-tensor were measured directly from paramagnetic resonance spectra of powdered samples and the average value of the g-tensor was also estimated from fitting the high temperature data ($T \gtrsim 20K$) to the Curie-Weiss law. EPR spectra of the glycine complex reflect the full g-tensor anisotropy with $g_1 = 2.08$, $g_2 = 2.14$, $g_3 = 2.25$, and $g_{av} = 2.14$. In contrast to the sharp well-resolved lines of $[Cu(N\text{-sal-gly})H_2O]\cdot 0.5H_2O$ the EPR spectrum of $Cu(N\text{-sal-}\alpha\text{-aiba})H_2O$ revealed only a single broad (~ 700 G) line centered near $g=2.17$; no temperature dependence of the EPR lines of either compound was observed down to 77K. The estimated values of $<g>$ from the susceptibility data for the glycine ($g = 2.11$) and aminoisobutyrato ($g=2.09$) complex were in agreement with these measured directly from the resonance data (see Table II).

DISCUSSION

Structural Data. The gross structural features of both complexes are very similar (see Table I).[36,37] As noted above, the prominent structural feature of both complexes is the presence of a zig-zag linear chain which is formed by the coordination of a "free" carboxyl oxygen atom from an adjacent molecule to the apical site of the roughly square pyramidal array of donor atoms about a particular copper ion. This leads to an unusual three-atom bridge, Cu-O-C-O-Cu, and a spiraling chain of copper(II)

ions running approximately parallel to the crystal b-axis. In Figures
7 and 8, projections onto the bc plane of the unit cells of both complexes
are shown. The bends which propagate the chain running the b-axis are
blackened or dashed for clarity. This arrangement leads to the result
that the copper-copper separation (5.33Å) within a chain in the glycinato
complex is substantially longer than the copper-copper separation between
chains (5.00Å). In the aminoisobutyrato complex, the reverse situation
obtains, with the intrachain copper-copper distance (4.85Å) being shorter
than the interchain distance of 5.00 Å. It is of further interest to
note that in Cu(N-sal-α-aiba)H$_2$O, nearest-neighbor copper ions within a
given chain are crystallographically and magnetically independent of each
other while copper ions in different chains are related by inversion cen-
ters. Thus, an antisymmetric exchange term of the form $D(S_1 x S_2)$ will be
allowed along the chain but forbidden between chains.[43] In the glycinato
complex, such a term is allowed along the chain and between the nearest-
neighboring chains but forbidden between next-nearest neighboring chains.

Since the molecules within a chain spiral along the b-axis, relatively
close interchain contacts are established between the coordinated water
molecule of one copper atom to the phenolic or carboxyl oxygen atoms of
a neighboring chain. These interactions are of prime importance in the
glycinato complex since the relative positions of the coordinated water
molecule (W1) and the 'free" water molecule (W2) allow extensive hydrogen-
bonding between chains.[46,47] A view (along the b-axis) of two copper
ions in different chains in the glycinato complex is shown in Figure 9.
The distances from the phenolic oxygen atoms (O1 and O1') to the hydrogen
atoms of the neighboring coordinated water molecules (W1 and W1') are

2.61Å (dashed line). In addition, the "free water molecule (W2) which
is situated on a two-fold axis forms weak hydrogen bonds to the apical
carboxyl oxygens (03 and 03') of 2.95Å and to the hydrogen atoms of the
coordinated water molecule of 2.30Å. In the aminoisobutyrato complex,
similar close contacts of 2.67Å exist between an in-plane carboxyl oxygen
and the oxygen atom of the coordinated water molecule of a neighboring
chain. However, the relative orientation of the chelate rings and the
absence of a water molecule between chains lead to no additional close
contacts in the aminoisobutyrato complex.

Magnetic Data. The Hamiltonian for an isotropic Heisenberg exchange
interaction of a spin-pair system in a non-zero applied magnetic field is
given by

$$H = -2J\hat{S}_1 \cdot \hat{S}_2 + g\beta HS + D[S_z^2 - S(S+1)/3] + E(\hat{S}_x^2 - \hat{S}_y^2) \quad (1)$$

where $\hat{S}_1=\hat{S}_2$ are the spin operators, $S = S_1+S_2$ is the total spin, and
H is the applied magnetic field. The parameters D and E are zero-field
splitting tensors of the S=1 state. Thus, in zero applied field, the
isotropic exchange interaction $(-2JS_1 \cdot S_2)$ couples the spins S_1 and S_2
into a new set of states of singlet and triplet spin multiplicity, and,
these states can be further split by the Zeeman interaction in an applied
magnetic field (neglecting the smaller D and E terms). In this particular
example, an exact expression for the magnetization can be easily derived,
and the magnetization per mole of S=1/2 ions is given by Equation 2.[15]

$$M = \frac{Ng\beta \sinh(g\beta H/kT)}{\exp(-2J/kT) + 2\cosh(g\beta H/kT) + 1} \quad (2)$$

Interactions which may give rise to deviations from the pair model (inter-
pair exchange, etc.) must be accounted for by a molecular field correction

term (3)

$$H_{eff} = H + \gamma M \tag{3}$$

where M is the magnetization resulting from the effective field and the isotropic exchange interaction, and γ is the molecular field parameter. Equations (2) and (3) may be solved by repeated iteration until a self-consistent solution is found.[15,41,42]

We have fitted the observed magnetization versus temperature data (H=10kOe) for $[Cu(N-sal-gly)H_2O]\cdot 0.5H_2O$ to Equations (2) and (3), and find remarkable agreement with pair model over the entire temperature range (1.6-160K). Attempts to describe a susceptibility, $\chi = M_{obs}/H$, in terms of the isotropic linear chain model of Bonner and Fisher[44] failed. Thus, in moderate magnetic fields (H~10kOe), the pair model provides an excellent fit to the observed data with g = 2.089 $\pm$ 0.003, 2J = -4.38 $\pm$ 0.02 cm^{-1} and γ = -0.63 $\pm$ 0.033; the mean fractional deviation (MFD), defined as $\Sigma[(|M_{obsd}-M_{calcd}|)/M_{obsd}]/N$, , where N is the number of observations, of a data point from the theoretical curve was 0.787×10^{-2} for this fit. Within the molecular field approximation, γ is related to the interpair exchange by

$$Z'J' = \frac{\gamma N g^2 \beta^2}{2} \tag{4}$$

where Z' is the number of nearest neighbors and J' is the interpair exchange energy. Since the number of nearest neighbors, Z', is four for a c-centered cell, a very small interpair exchange, J' =-0.089 cm^{-1} may be calculated.

Since Bonner et al.[23,24] had noted that the effects of the additional exchange interactions became more significant when $Cu(NO_3)_2\cdot 2.5\ H_2O$ was

placed in strong magnetic fields, we have measured the isothermal magnetization of $[Cu(N\text{-}sal\text{-}gly)H_2O]\cdot 0.5H_2O$ at temperatures above and below T_{max}. In agreement with the observations of those authors, we found that increasing deviations from the simple pair model in Equations (2) and (3) were apparent in applied magnetic fields approaching $H_{cross} = |2J|/g\beta$. Thus, the best fit to the T=4.2K isotherm yields $g = 2.11 \pm 0.02$, $2J = 4.22 \pm 0.10$ cm^{-1} and $\gamma = -2.24 \pm 0.40$ with the sum of the squares of the deviation, SD $= \Sigma(|M_{obsd} - M_{calcd}|)^2/M_{obsd}^2$, being 0.312×10^{-4}. The major reason for including a much larger molecular field term was to fit the data above about 35 kOe more precisely. In further agreement with the above observation, the isotherm at 1.72K required a still larger molecular field term, but within the precision of the fit nearly identical values for the singlet-triplet splitting were obtained; the parameters for this fit are $g = 2.10 \pm 0.04$, $2J = -4.22 \pm 0.30$ cm^{-1}, $\gamma = -2.42 \pm 0.60$, and SD $= 0.192 \times 10^{-3}$. Since strong magnetic fields will alter the population of the excited triplet state and eventually change the multiplicity of the ground state (at H_{cross}), the additional pathways for exchange, which are some two orders of magnitude smaller in moderate applied fields, become increasingly more important in strong fields at very low temperatures. In view of the chain-like arrangement of copper ions in this complex, it is tempting to attribute the enhanced interaction to superexchange along the one-dimensional path.

The observed magnetization versus temperature data for Cu(N-sal- α-aiba)H_2O were fitted to Equations (2) and (3), and only a marginal fit to this model was obtained with $g = 2.09 \pm 0.03$, $2J = -0.81 \pm 0.20$ cm^{-1},

$\gamma = -2.03 \pm 1.0$, and SD = 0.239×10^{-2}. The absence of a singularity in the observed data, i.e. a maximum in M, made fitting difficult since fairly substantial changes in the parameters caused little change in the quality of the fit. It is surprising that the observed interaction is apparently so much smaller in this compound than in the glycinato analogue since the contacts between chains are comparable. However, in this compound, the inter-chain copper-copper distance (5.00Å) is longer than the intrachain distance (4.85 Å). If the exchange pathway along the chemical chain is predominant, then one might expect a linear model to be more appropriate. To investigate this possibility, the data for Cu(N-sal-α-aiba)H$_2$O were compared to the linear Heisenberg chain model using the high temperature series expansion of Baker et al.[45] Upon truncating the observed data to those above 4.2K and defining a susceptibility as $\chi = M_{obsd}/H$, a rather poor fit to the observed data yielded g = 2.05 ± 0.04, J = -0.74 ± 0.30 cm^{-1}, and SD = 0.33×10^{-2}. Thus, within the limits of the fitted parameters, a clear choice of the appropriate model cannot be made. Most likely neither the pair nor the linear model are truly appropriate since the structural data suggest that the two exchange pathways are comparable.

It is of interest to compare the possible pathways for the super-exchange interactions in these compounds. Apparently the large intrachain distances and a three-atom bridging arrangement make exchange along the chains quite weak. In the glycinato complex, this intrachain mechanism leads to very weak interactions, and the observed exchange involves super-exchange through the extensive hydrogen bonds between ions in different chains. The presence of a "free" water molecule (W2) situated between chains and the relative orientation of the chelate rings in the glycinato

complex makes this <u>interchain</u> pathway considerably more favorable. Thus, in moderate magnetic fields the magnetic properties of the glycinato compound are readily described by a dimeric model. In contrast, the structural features of $Cu(N-sal-\alpha-aiba)\cdot H_2O$ suggest that the two exchange pathways are comparable since the intrachain copper-copper distances are longer and the interchain hydrogen bonds are somewhat weaker than in the glycinato complex.

CONCLUSION

The observed magnetic properties of $[Cu(N-sal-gly)H_2O]0.5H_2O$ can be readily described by a simple pair model coupling two copper(II) ions even though on additional higher dimensional pathway is present. The singlet-triplet splitting of about 4.4 cm^{-1} allows a field induced ground state change in strong applied fields such that $H_{applied} > 2J/g\beta$. Increasing deviations from the pair model are observed in strong fields and very low temperatures, and these deviations can be ascribed to longer-range interactions among the newly induced ground states of the antiferromagnetically coupled pairs. Thus, experiments such as cooling by adiabatic demagnetization[18-25] should be possible for this complex. In addition, it should be possible to observe long-range three-dimensional ordering at very low temperatures over a small range of effective fields near the singlet-triplet crossing. Recent work on $Cu(NO_3)_2\cdot 2.5H_2O$[26,48], whose gross structural features are very similar, has shown that long range antiferromagnetic ordering does occur at 0.175 K in fields of about 36 kOe. In $Cu(NO_3)_2\cdot 2.5H_2O$ two additional exchange pathways

exist (other than the pair-wise interaction), and the choice between an alternating chain and spin ladder model cannot be made easily. The structural differences of $[Cu(N-sal-gly)H_2O]0.5H_2O$ versus the nitrate salt are unique in this respect since only one additional exchange pathway exists, namely the "obvious" chemical chain.

The situation in $[Cu(N-sal-\alpha-aiba)H_2O]$ is more difficult to describe a combination of subtle structural variations outlined above apparently has dramatically modified the strength of the magnetic interactions. Thus, while similar paths between chains exist, the intrachain pathways becomes important because the shortest copper-copper distance is along this path. Our work cannot make a clear choice between the dimer and linear chain models. Very low temperatures (< 1K) measurements are required to verify the appropriate magnetic model.

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TABLE I. Selected Structural Data

Amino Acid	Space Group	Z No. Molecules per cell	Cu-Cu intrachain Å	Cu-Cu Interchain Å	Z' number of nearest neighbors
glycine	C2/c	8	5.33	5.003	4
α-aminoisobutyric acid	$P2_1/c$	8	4.85	5.00	~4

TABLE II: Magnetic Parameters for Cu(N-sal = α-AA)H$_2$O

| Amino Acid | Curie-Weiss Law | | | Best Fit Parameters | | | | |
	$\langle g \rangle$ EPR	$\langle g \rangle$	θ, °K	J, cm⁻¹	g	Y	J', cm⁻¹	Model
glycine	2.16	2.11	-3.2	-2.195±0.002	2.09±0.003	-0.63±0.035	-0.089	pair, Eq. 3 64 M vs. T
				-2.11±0.05	2.11±0.02	-2.24±0.40	-0.32	pair, T=4.2 isotherm
				-2.11±0.15	2.10±0.04	-2.42±0.60	-0.35	pair, T=1.72 isotherm
α-aminoiso-butyric acid	2.17	2.09	-1.5	-0.81±0.2	2.09±0.03	-2.03±1.0	-0.29	pair M vs. T
				-0.74±0.3	2.05±0.41	-	-	Linear chain ref. 44,45

FIGURE CAPTIONS

Figure 1. The generalized molecular structure of the copper Schiff base chelates derived from salicylaldehyde and α-amino acids. The oxygen atom marked by an asterisk is the "free" carboxyl oxygen which propagates the linear chain.

Figure 2. The experimental magnetization versus absolute temperature (squares) at a constant applied field of 10kOe. The theoretical curve is the best fit to Equations (2) and (3) with parameters listed in Table II.

Figure 3. An expanded scale view of the lowest temperature data from Figure 2.

Figure 4. A sketch of the zero-field exchange energy versus Zeeman energy for a weakly coupled pair of spins. The exchange energy, 2J, is negative and the S = 0 state is colinear with the horizontal axis.

Figure 5. High-field isothermal magnetization data for the glycinato complex. The solid lines represent the best fit to Equations (2) and (3) with the parameters listed in Table 2.

Figure 6. The observed constant field (10kOe) magnetization versus temperature for the α-aminoisobutyrato complex. The theoretical curve is the best fit to the dimer model in Equation (2) and (3) (see text for discussion of the parameters).

Figure 7. A projection of the unit cell of the glycinato complex onto the bc-plane. The bonds which propogate the chains running parallel to the b-axis are blackened. The labeling scheme
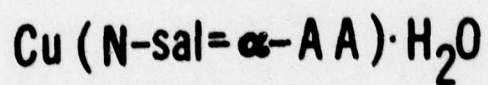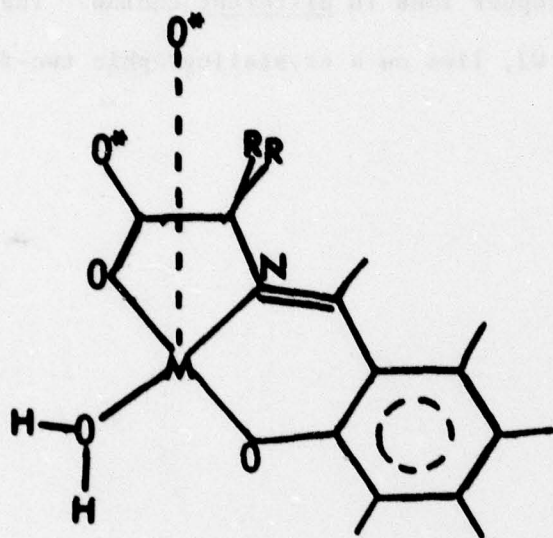
Figure 7 (cont.)

    is that of Reference 36, and W1 and W2 represent the coord-

    inated and "free" water molecule, respectively.

Figure 8. A projection of the unit cell of $Cu(N$-sal-α-aiba$)H_2O$ onto

    the bc-plane. Only atoms bonded to copper are labelled.

    The two chains which spiral along the b-axis are blackened
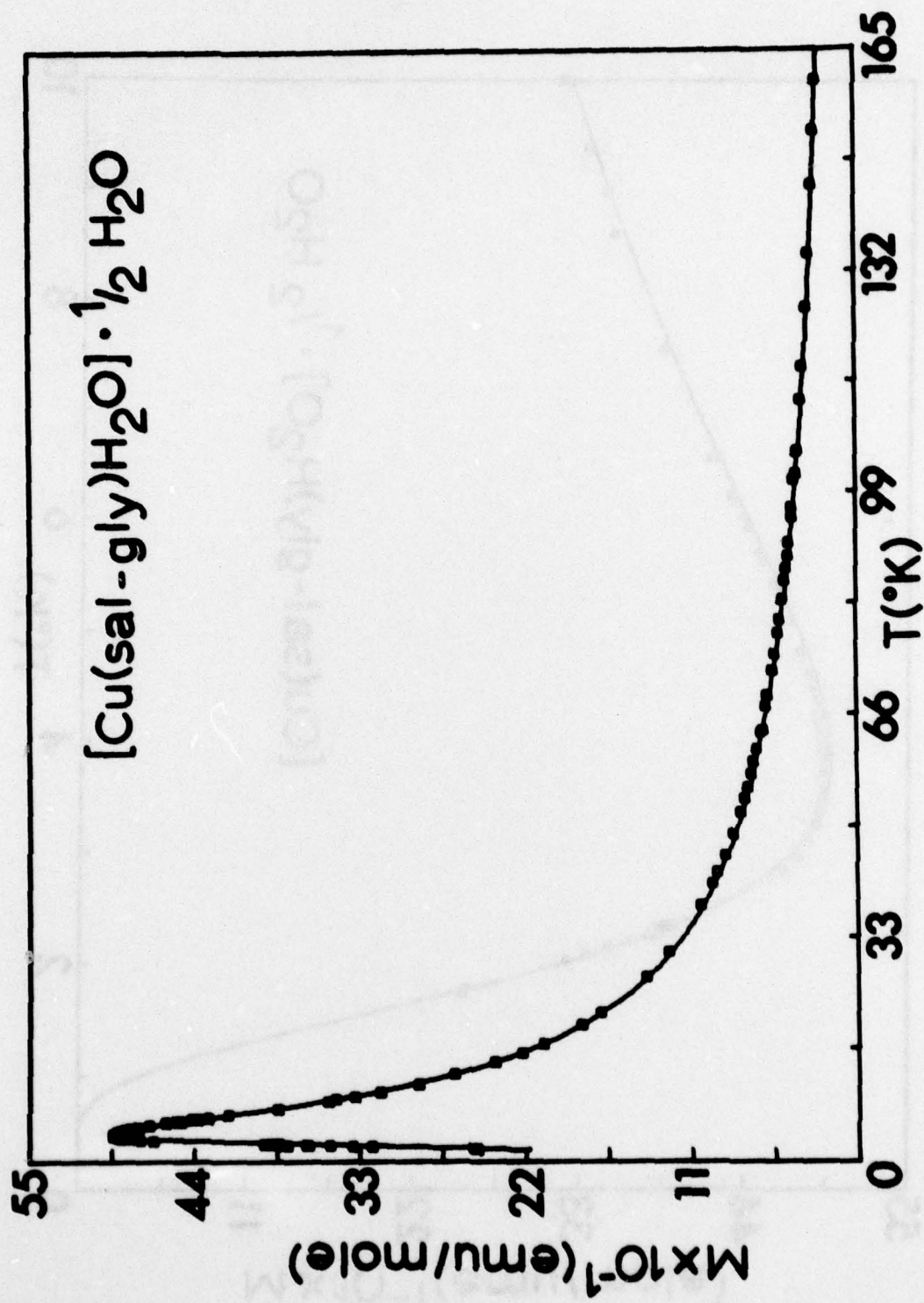
    and dashed for clarity.

Figure 9. A projection along the b-axis showing the close contacts

    established between copper ions in _different_ chains. The

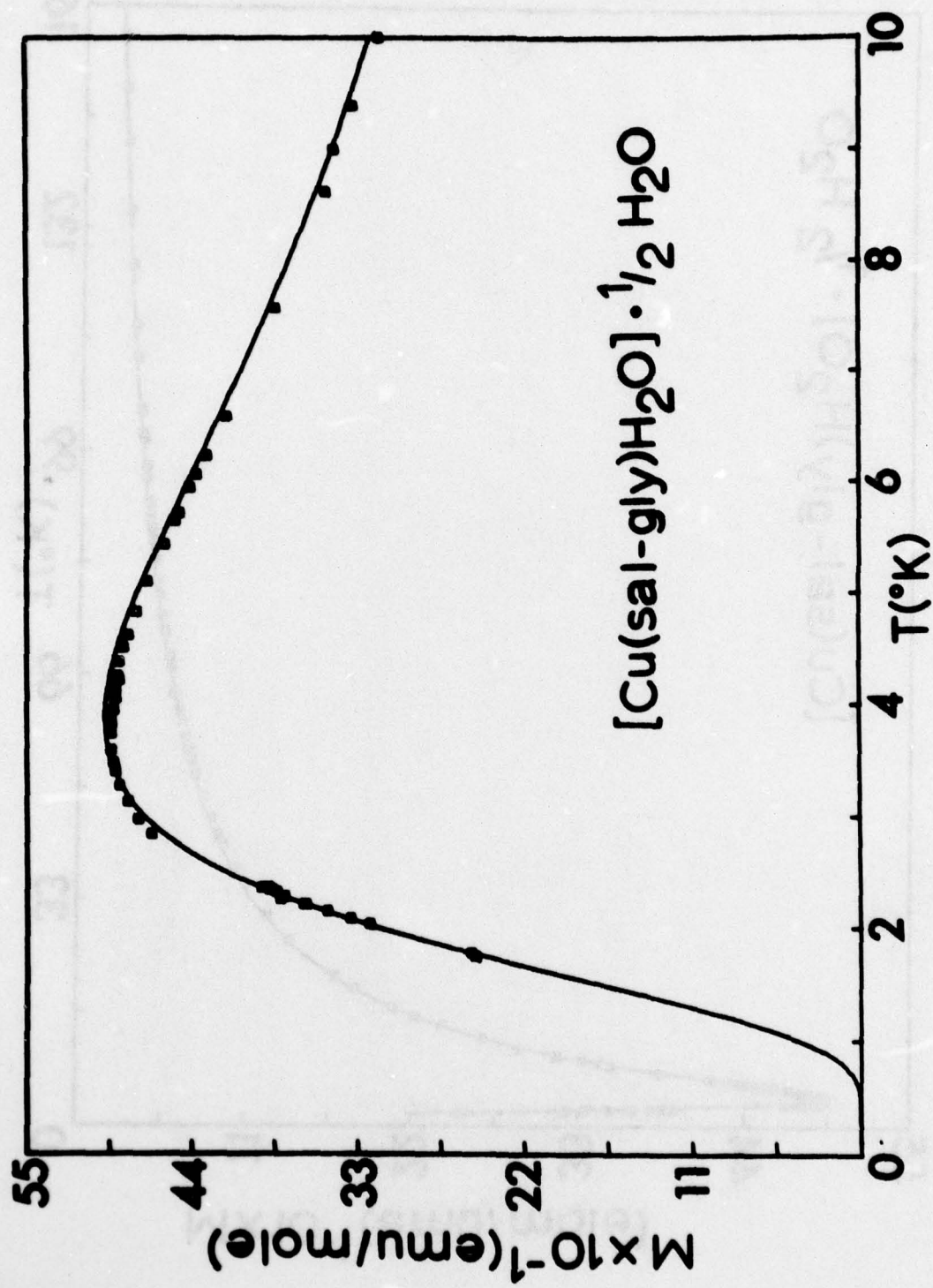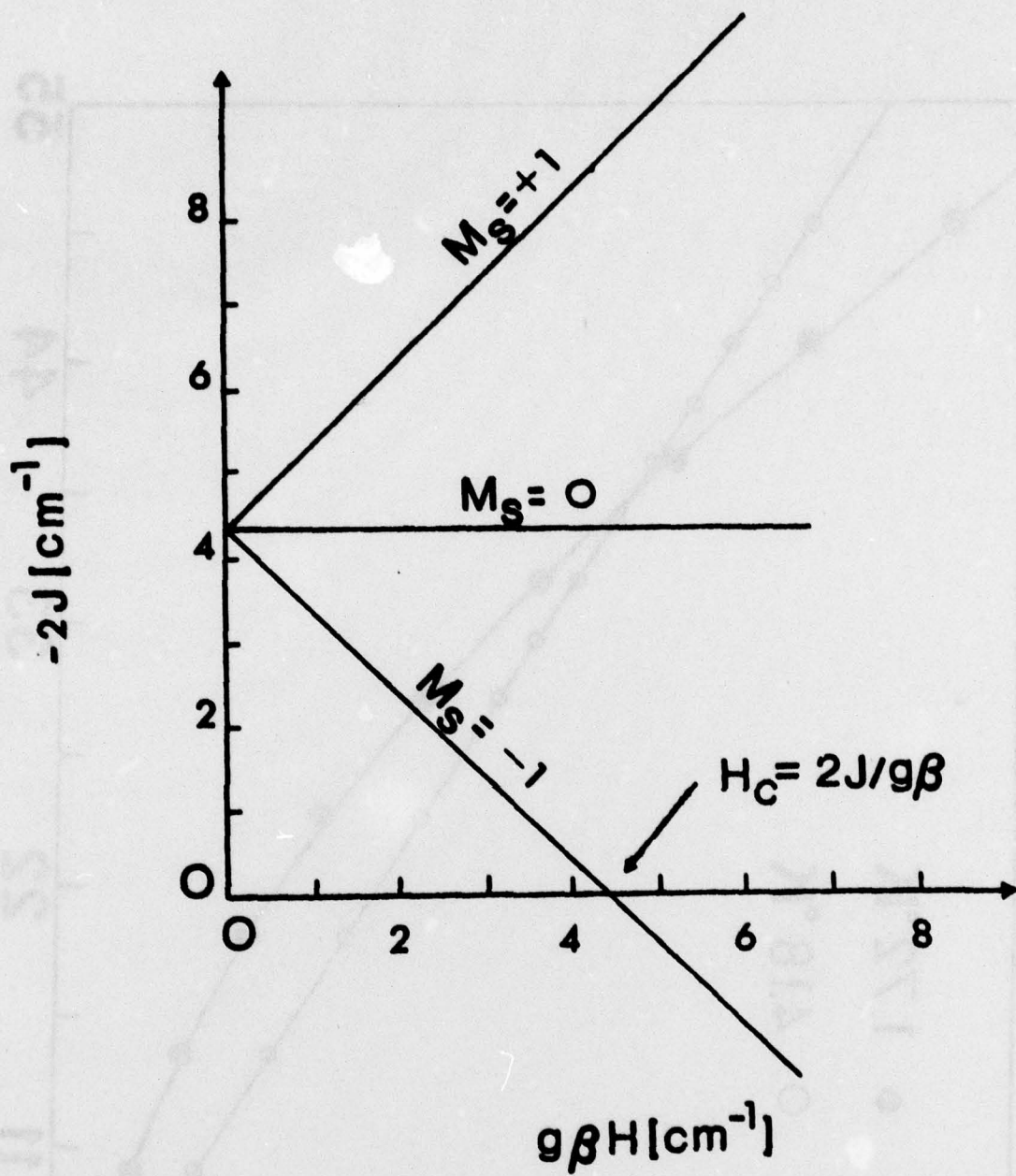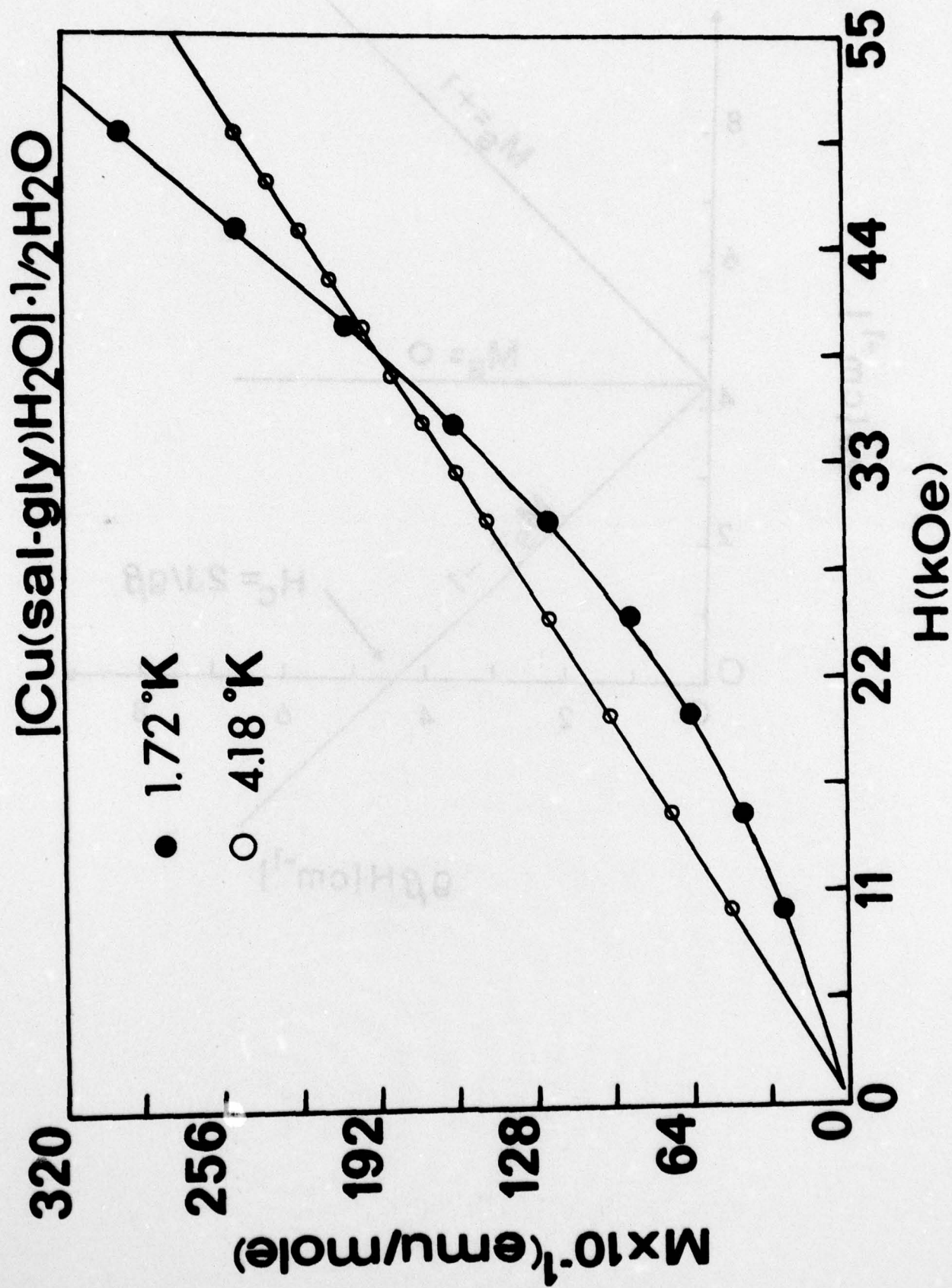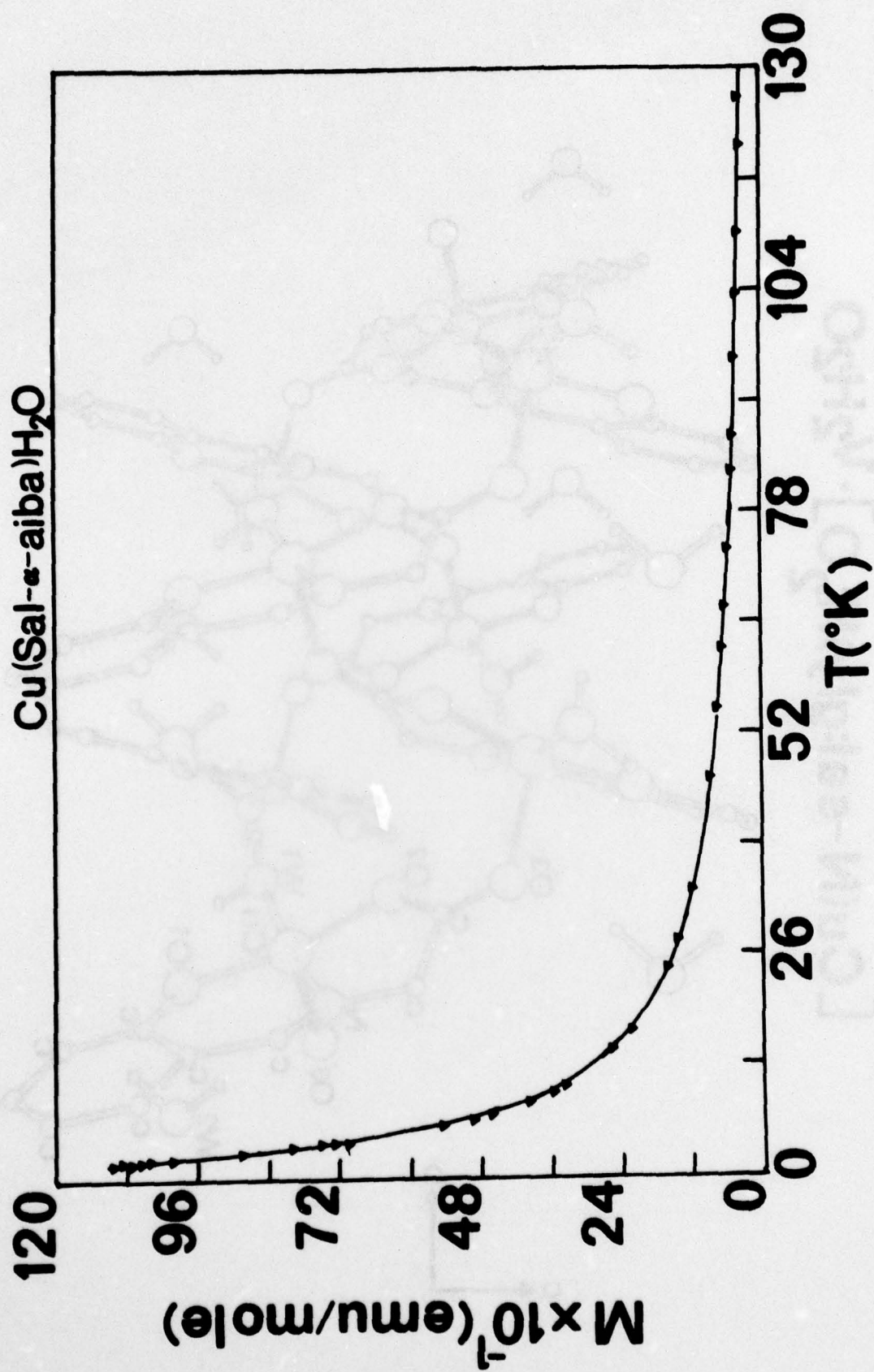   free water molecule, W2, lies on a crystallographic two-fold

    axis.

$Cu(N\text{-}sal=\alpha\text{-}AA)\cdot H_2O$
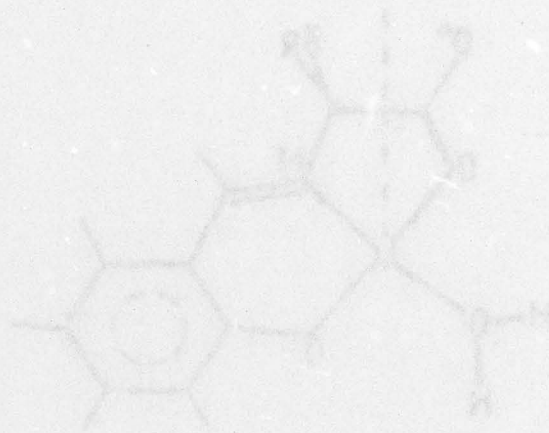
$AA = glycine, R=H$

$AA = \alpha\text{-}aminoisobutyric\ acid, R=CH_3$

$[Cu(sal-gly)H_2O] \cdot \frac{1}{2} H_2O$

$[Cu(sal-gly)H_2O] \cdot \frac{1}{2} H_2O$

[Cu(sal-gly)H2O]·¹/₂H2O

Cu(Sal-α-aiba)H₂O

$[Cu(N-sal:gly)H_2O] \cdot \frac{1}{2}H_2O$

Cu(N-sal-α-iaba)H₂O

W = H₂O

b

c

$[Cu(N-Sal=gly)H_2O]\cdot\frac{1}{2}H_2O$